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The ShanghAI Lectures: A Global Education Project on Artificial Intelligence[1]

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Abstract: We present a global education project in Artificial Intelligence (AI) called the "ShanghAI Lectures": A lecture series held annually via videoconference among 15 to 20 universities around the globe. The lectures are complemented by a novel three-dimensional collaborative virtual environment for international student teamwork, and a web-based resource designed as a knowledge base and for community building. This paper summarizes the lessons learned from the first edition of the ShanghAI Lectures, which may guide future global teaching and learning projects of this kind.

Keywords: Global Teaching, Intercultural Learning, Videoconference, 3D Collaborative Virtual Environments
Categories: L.2.7, L.3.0, L.3.5, L.3.6, L.5.0, L.6.1, L.6.2

1 Introduction

Globalization and emerging technologies for remote collaboration have led to new developments in work and education during the last few decades, and will continue to profoundly influence working, teaching, and learning in the 21st century. Since communicating with others is no longer bound to physical co-presence, traveling is often not necessary anymore (apart from issues such as carbon footprint, increasing costs and risks). Thus, virtual collaboration across national borders is becoming increasingly popular. We present a pioneering project in academic globalization that

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1 Part of this research has been presented as a conference paper entitled "The ShanghAI Lectures: A case study in global education" at the Immersive Education (iED) Summit, Boston College, Boston, MA, USA, May 13-15, 2011.

aims to prepare students for a global work environment, and to provide them with a platform for practicing the effective use of novel collaboration technologies.

The Artificial Intelligence Laboratory of the University of Zurich presented a global lecture series on natural and artificial embodied intelligence [Pfeifer, 06; Pfeifer, 07] called The ShanghAI Lectures (http://shanghailectures.org). This annual lecture series was presented for the first time in fall term 2009 from Shanghai Jiao Tong University, connecting 18 universities worldwide via videoconference. In addition to knowledge dissemination to a global audience, the ShanghAI Lectures aimed to bring students and researchers from different countries and disciplines together who otherwise would not share common activities. In order to comply with these goals, we employed a three-dimensional collaborative virtual environment (3D CVE) for international student collaboration, and designed a web-based resource as a sustainable knowledge base and platform to build an international, multidisciplinary community on embodied intelligence.

In this paper we describe the three constituents of the ShanghAI Lectures project: (1) the lectures, (2) the web-based resource, and (3) the 3D CVE, and report on our lessons learned regarding each of these components. We also present the evaluation results of students' feedback collected in a survey at the end of the lecture series in early 2010. The evaluation of this global education project not only serves as a basis for follow-up editions of the ShanghAI Lectures but also aims to provide guidance for future global education projects of this kind.

2 Lectures

The lecture series gives an overview of natural and artificial forms of intelligence and introduces the notion of "embodiment", a concept which studies the role of the body in the development of intelligent behavior. This has implications not only for science and technology—robotics, artificial intelligence, behavioral and neuroscience—but also for society at large. Therefore, the lectures are designed for a broad audience, not just engineers or computer scientists.

Most of the ten two-hour lectures were split into two parts: The first hour was reserved for the actual lecture on embodied intelligence. The second hour was filled with (usually two) guest presentations by lecturers from one of the regularly participating universities or from "one-time" participants who connected to the videoconference for giving a guest talk.

Videoconference and screen sharing were used as the main channels to enable the sites to participate in the interactive lectures. Text chat was established as a third connection for "background communication."

All lectures were recorded and made available on the project website, along with recordings of guest talks, which were either held live in one of the videoconference sessions or prerecorded and submitted for inclusion in a "talk repository" on the project website (see section 3).

2.1 Videoconferencing

Videoconferences enable participants to remotely join a common meeting or lecture, even though they are located far from each other. However, different time zones might pose a problem in planning the meeting schedule, and indeed some universities could not participate in the videoconference due to time differences.

From a technological point of view a videoconference is rather straightforward, at least in principle (see Fig. 1 for two examples of how lecture halls were set up). While several competing videoconferencing technologies are available, one of the most popular and widespread is H.323, a collection of communication protocols for handling the connection, compression and transmission of the audio and video data in a packet-based network (i.e., the Internet). One advantage of H.323 is that compatible equipment is already available in many universities, which made it easier to bring together the participants in the ShanghAI Lectures. Another advantage is that in a multipoint connection (i.e., in a meeting with more than two sites), participants with different bandwidths can connect to the same conference.

Bandwidth determines the quality of the audio and video signals that a participating site sends and receives. Sites connecting with a lower bandwidth only get a reduced video resolution and low-quality audio. High-definition (HD) videoconferencing had been introduced a few years ago. However, we decided to resort to standard definition video for compatibility reasons, as most of the participating sites did not have HD equipment or the necessary bandwidth anyway.

In a multipoint videoconference, the participants are connected via a so-called Multipoint Control Unit (MCU) that mixes and distributes the audio/video signals. The number of participants is only limited by the capabilities of the MCU, irrespective of the bandwidth available to the individual sites. The MCU also controls the screen layout the participants receive, that is, how the video frames are arranged. Three screen layouts were used for the ShanghAI Lectures: (1) during a lecture, the main speaker is displayed in a big frame with some of the other sites visible on the side and below; (2) when showing videos and animations, they are displayed in full-screen mode, effectively hiding all other sites; and (3) during discussions, the two main parties are placed next to each other, surrounded by smaller frames of the other sites.

Multipoint videoconferences raise several issues that are often neglected. Most importantly, echo canceling becomes essential. If one site does not use an echo-canceling audio system, all the other sites hear a feedback (echo). Each site is required to mute their microphones when not speaking in order to avoid audio problems in all the other sites. Although it is possible to mute sites on the MCU using a web-based interface, this procedure is too slow, especially in a discussion. Therefore we had to enforce a strict policy that all participants turn off their microphones when not talking.

Another issue lies in the fact that each time a site connects or disconnects, there is an audible signal and the screen layout updates (although it might be possible to change this behavior on the MCU). In order to avoid this disturbance, we asked all sites to connect well before the actual lecture starts. However, due to network problems, some sites occasionally “dropped out” and had to be “dialed in” again during the course of a lecture.

SWITCH (http://www.switch.ch), the Swiss Education and Research Network, provided the MCU for the ShanghAI Lectures. Their MCU can handle up to 20 concurrent users. However, three slots are normally reserved for technical purposes, so we were limited to 17 participating sites per lecture. This was no problem, as the above-mentioned 18 participating sites were not connected at the same time. About 12 sites participated regularly, one MCU slot was reserved for the recording (see 2.4 below), and the remaining slots could be used for guest presentations.

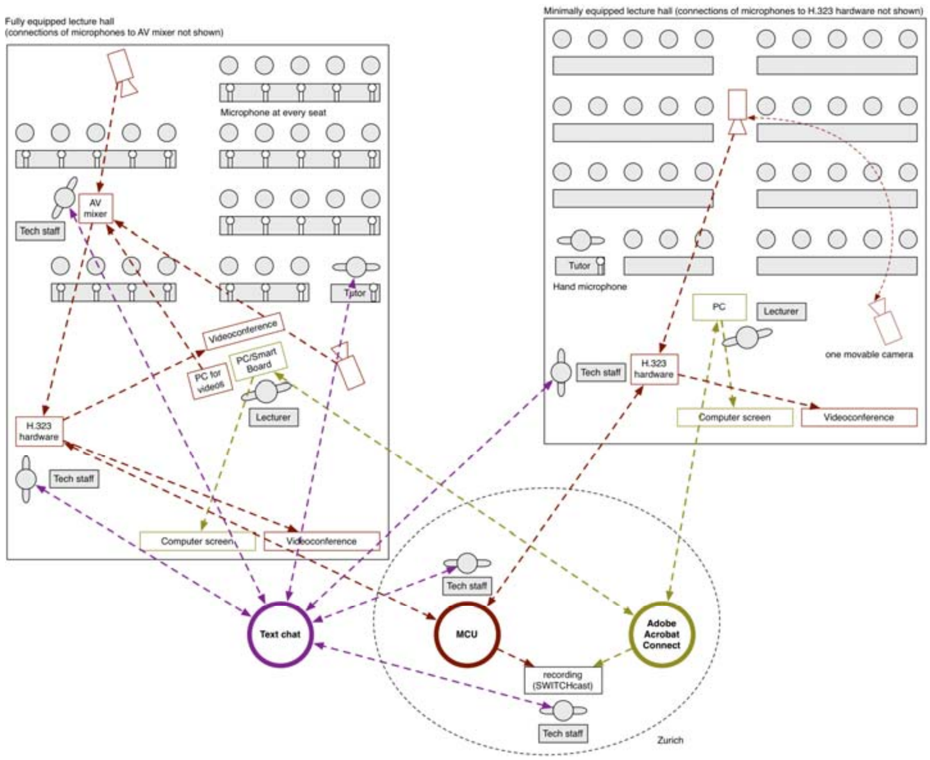

Figure 1: ShanghAI Lectures videoconference setup (left: fully equipped lecture hall; right: minimally equipped lecture hall)

2.2 Screen Sharing

All lecturers used electronic slides for their presentations, which had to be shared among the participating sites. While there is an addition to the H.323 standard that allows for parallel transmission of computer screen data (H.239), it depends on each site's equipment whether they can use this option. In order to ensure compatibility, we resorted to a software solution, Adobe Connect, that enabled all presenters to share their screens with the other participants. This software, based on the Flash plug-in for web browsers, offers much more functionality, such as text chat, whiteboards, and even webcam-based videoconferencing. However, we did not make use of these features, as we intended to keep the communication streams (i.e., videoconference, chat, etc.) separate from each other to introduce some redundancy. As with the videoconference, SWITCH provided the infrastructure (Adobe Connect server and software licenses) for the ShanghAI Lectures.

While this screen sharing solution has the advantage of being simple to setup and transparent for the users (once they are connected to the system, the lecturers can give their presentation as usual, as the software runs in the background), it can only transmit visual data at a rate of a few frames per second. In other words, animations and videos do not display smoothly and sound cannot be heard; if lecturers wish to show videos, they have to be broadcast over the videoconference channel. The system we used for recording the lectures (see 2.4 below) also made it necessary to limit the screen sharing to static images. For these reasons, we set up an audio/video mixer in the main lecture hall that connected a dedicated computer to the H.323 hardware. All lecturers were asked to send their movie files to the main site's lecture staff who then played the videos on that computer, feeding the audio/video into the videoconference.

2.3 Text Chat

We found it very important to have a communication channel open that does not interfere with the videoconference. Therefore, every participating site was required to have at least one technician online in a text chat program, so that we were able to quickly communicate in the background without disturbing the conference.

There are many commercial text chat systems available, most of which are not compatible with each other. As we did not want to force participants into one particular system, some operators had up to four chat programs open during the ShanghAI Lectures: Google Talk, Yahoo, AIM, and MSN. We did not use Skype, even though it is one of the most popular chat systems, because we wanted to keep the bandwidth requirements as low as possible.

2.4 Recording

The lectures were made available on the project's website using SWITCHcast (https://cast.switch.ch), a collection of tools and practices provided by SWITCH. Originally intended for recording normal classroom-based lectures, the SWITCHcast Recorder software combines the audio/video from the classroom's camera and microphone with the screen image from the lecturer's computer and then uploads these data streams to the SWITCHcast server for further editing. Using a web interface, unwanted scenes can be cut out, chapter markers can be added, and then the recording can be published in three formats: Streaming Flash video, downloadable QuickTime movie, and iPod-formatted "podcast" movie. Right after each lecture, we edited and published the recording, so that it would be available as quickly as possible. Some universities outside of the "compatible" time zones for real-time participation in the videoconference, followed the course of the lectures by watching these recordings and only participating actively in the international group exercises (see 4.2 below).

2.5 Evaluation Results of the Lectures

In a survey that was administered after the 2009 lecture series in early 2010, students rated a list of predetermined suggestions on how the presentation style and interactivity level of the lectures could be improved for future events. Of 282 actively participating students, roughly one third filled in the questionnaires.

63% indicated that they enjoyed attending the videoconference in their local lecture hall and that nothing should be changed regarding the presentation style of the lectures. 37% indicated that they would prefer to watch the lectures from home in real time.

Regarding the interactivity level, 54% of the students indicated that they enjoyed attending the lectures the way they were presented during the ShanghAI Lectures. 46% would have preferred more interactive lectures (e.g., to have the opportunity of asking questions during the lectures).

3 Web-based Resource

The second component of the ShanghAI Lectures project was the web-based resource, which served several purposes: A platform for community building, distribution of recorded lectures, exercises, and related materials, and a repository of guest lectures. Instead of using a learning management system like Moodle, we decided to use Joomla, an open-source content management system for regular websites, which could be adapted and extended for our purposes.

3.1 Community Platform

Our aim was to bring hundreds of students and researchers from different cultural backgrounds and academic disciplines together during the lecture series, and to enable the emergence of a sustainable community around the topics of Embodied Intelligence, Robotics, Bionics, etc., beyond the ShanghAI Lectures course. Therefore, we offered community features on the website, such as individual profile pages, and a forum where students could discuss questions and comments on the topic of the lecture asynchronously with other participating students, lecturers, and researchers (see Fig. 2). In addition to a freely accessible repository of lectures and guest talks, registered members had the opportunity to contribute to a video gallery (e.g., showing latest developments in robotics labs).

3.2 Lecture Materials

The exercises and additional materials related to the lectures, as well as recordings of the lectures themselves, were made available on the website. Students could find instructions for individual and international group exercises, the schedule and content of the lectures, as well as information on their reading assignments. We assigned the students to groups of three to five members from different universities in which they collaborated on exercises over the course of the semester. The purpose of these international group assignments was to foster cross-border collaboration between the students and to obtain data on international virtual team behavior (see section 4). Teaching assistants from the participating universities corrected and graded the group exercises. Example solutions and grading schemes were provided by the team in Zurich.

Figure 2: Community feature (forum) on the ShanghAI Lectures website (2010, look and feel identical to 2009)

3.3 Repository of Guest Talks

In addition to the videoconference-based lectures, presentations contributed by guest speakers were uploaded to the website. The idea was to create a "repository" of talks by high-profile researchers in the area of natural and artificial intelligence. While we prepared a manual for these lecturers, so that they can record and upload their talks to the SWITCHcast system by themselves, most speakers submitted prerecorded movie files that we then uploaded and published in the SWITCHcast format.

The repository of guest lectures is still growing; as of May 2012 there are more than 100 talks available.

3.4 Evaluation Results of the Web-based Resource

The same sample of students (as stated above) filled in questionnaires after the 2009 series of the ShanghAI Lectures. They rated whether they preferred to watch the recorded lectures and talks individually or together with their international team members, and which features of the web-based resource they would continue to use after the lecture series ended.

49% indicated that they preferred to watch the recorded lectures individually, and 51% would prefer to watch them with their international team members. 64% of the students indicated that they would download and watch new lectures and guest talks in the future, 28% would continue to post and respond to comments and questions in the forum, and 25% would continue to contribute to the video gallery, that is, uploading their own videos.

4 Collaborative Virtual Environment

While videoconferences and web-based platforms are not very new "tools," the novel component in the ShanghAI Lectures project is the use of a 3D CVE, a virtual world that is used as a platform for international student collaboration. The basic working principle of virtual worlds is that users log in as avatars (virtual embodied representations of themselves) from anywhere they like, provided the infrastructure (i.e., bandwidth and hardware equipment) is sufficient, and interact with others in a three-dimensional, fully configurable virtual environment. In contrast to videoconferencing, 3D CVEs provide a variety of interaction possibilities. For example, the users' virtual embodiment and the ability to move and navigate can be used as a nonverbal communication channel in parallel to voice and text chat. Interactive objects in the virtual environment can support and foster collaboration tasks and make working and learning in virtual worlds more motivating and engaging. Research has further shown that the visual character of virtual worlds increases memorability and retention [Schmeil, 09a; Schmeil, 12].

Virtual worlds, such as Second Life from Linden Labs, which were mainly developed for socializing and entertainment, are also increasingly being used for educational purposes [Hinrichs, 11]. We evaluated a number of virtual world technologies and decided to use the Open Wonderland framework (OWL; http://openwonderland.org) for several reasons that are discussed below. Originally developed by Sun Microsystems under the name Project Wonderland, OWL was released to the open source community under the new name after Oracle Corporation had bought Sun.

4.1 UNIworld

On the basis of OWL we developed a 3D CVE called UNIworld, which included a custom design of the environment (providing meeting rooms for the student groups, presentation stages, and common spaces) as well as a data acquisition system that enabled us to track avatar behavior in the virtual world. Students would log in to UNIworld in order to communicate and collaborate with their peers from participating universities all over the world.

OWL had been designed as a collaborative environment platform and therefore includes tools which are useful for team meetings and collaboration, such as a PDF viewer, whiteboard, and sticky notes. In addition, basically any X11 based application, for example, a word processor or a web browser, that is installed on the server can be used inside OWL. An application window appears as an object in the environment, and avatars can manipulate it by "taking control" in order to use the application. This enables avatars to collaborate on documents and look up information on the Internet without having to leave the virtual environment. Provided that the users wear stereo headsets, they have an immersive audio experience: An avatar's voice comes from the direction of where it is located, just as in the real world, and the volume decreases as it moves away from the listener.

Since OWL is an open source project, written entirely in the Java programming language, it has some key advantages: it is free to use, runs on all major operating systems, and can be adapted and extended relatively easily. There is a growing community of end users, many of them active in education (http://immersiveeducation.org and the newly founded European iED chapter, http://europe.immersiveeducation.org), and programmers who contribute new functionality in the form of modules (http://openwonderland.org/modules/module-warehouse). We are currently in the process of contributing our own developments for UNIworld back to the open source community behind OWL.

As OWL is still far from a final product (currently at version 0.5) it also has some limitations, namely, the maximum number of concurrent avatars on one server was not sufficient to accommodate all students. We distributed the load by setting up several identically configured UNIworld servers, and assigning every student group to one particular server. In collaboration with Henn Architekten (http://www.henn.com) and Studio-B (http://studio-b.org), the landscape of the virtual world was designed with the configuration of student teams (Fig. 3) and server limitations in mind [Schmeil, 10].

We had 18 instances of UNIworld in 2009 with five team rooms allocated to each instance. Although this has led to a reduced server load, hardly any (unscheduled) interactions took place between the students in the 3D CVE.

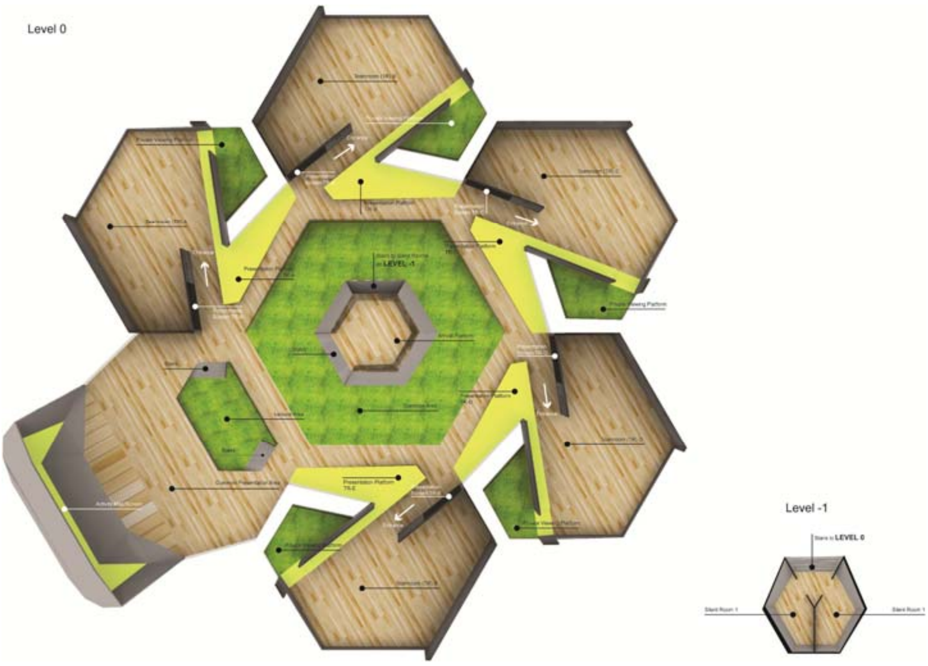

Figure 3: UNIworld design with common stage (lower left) and five team rooms

4.2 Group Exercises

UNIworld was mainly designed as a place for the student teams to work collaboratively on the exercises that accompanied the lecture series (Fig. 4). As such, the environment featured team rooms, in which the teams worked on biweekly exercises. These exercises were inspired by paper-based exercises from a former face-to-face version of the lecture and adapted for a 3D virtual world using the Avatar-Based Collaboration Framework [Schmeil, 09b]. Due to technical restrictions on the side of OWL and personnel shortage we succeeded in implementing only a limited number of engaging and novel collaborative learning tasks and activities. Nevertheless, exercises ranged from watching and annotating videos and images to staging and delivering interactive role playing performances and from voting by feet to riding on virtual robots. A small number of experimental and voluntary exercises were carried out in another open-source 3D CVE based on OpenSim.

For collaborative learning in UNIworld to run smoothly it is crucial that each participating university provides their students with access to the 3D CVE from a local computer lab, as well as technical support.

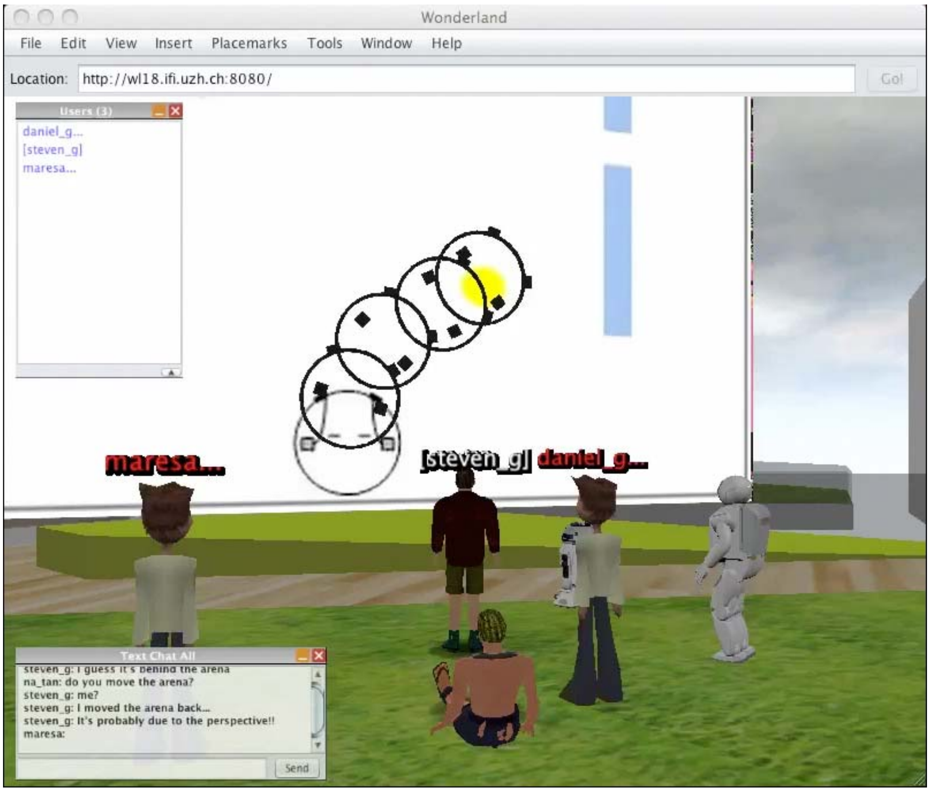

Figure 4: Group exercise in UNIworld

4.3 Evaluation Results of UNIworld

As part of the final evaluation of the 2009 series, students provided suggestions for mandatory and "nice-to-have" improvements of UNIworld in the form of free-text responses.

33% mentioned software fixes as mandatory improvements (e.g., stability and robustness of UNIworld, problems with avatar navigation, voice communication, and speed of shared applications), followed by 22% who mentioned network problems and requested lower requirements regarding Internet speed, and 11% who requested to reduce hardware requirements (e.g., graphics card) and hardware incompatibilities (e.g., microphones). 21% requested a more user-friendly interface, different or additional tools for collaboration (e.g., chat history, log of users who visited UNIworld, meeting schedule planner) or suggested improvements regarding the environment (e.g., nicer graphics, larger meeting rooms, more privacy for team meetings). 9% suggested using different media for collaboration if the task does not necessarily require a three-dimensional space. 5% had no suggestions for mandatory improvements.

As "nice-to-have" improvements, 27% requested a more intuitive user interface (e.g., easier object manipulation) and better user guides (e.g., tutorials). 25% suggested better or additional collaboration features (e.g., display of members' time zones, screen sharing function, pointer to distant spots, and "undo" buttons). 16% requested better graphics quality. 12% suggested changes in the virtual environment (e.g., more interesting/fun places to visit, private sections for team members, more space for teamwork). 11% asked for improved avatar customization (e.g., better avatar design, more individualistic features). 5% mentioned general technical problems that need to be resolved (e.g., better speed and performance). 4% asked for more advanced and practical collaboration tasks (e.g., building and simulating robots).

5 Discussion and Outlook

The current paper presented results from the student survey of the 2009 series of the ShanghAI Lectures. More general lessons learned from the first edition in 2009 are summarized in a project report (http://shanghailectures.org/project-report-2009). We will describe our improvement measures taken for the follow-up series of the ShanghAI Lectures, and discuss alternative design solutions for similar global education projects.

5.1 Videoconferencing

The videoconference proved to be quite stable, although some sites had problems with fluctuating bandwidth or configuration issues with their local equipment, such as noisy microphones or audio feedback. Most of these problems could eventually be resolved. Nevertheless, more disciplined testing beforehand would have largely reduced the number of errors. It is important that all involved technical staff understand their roles and responsibilities, so that issues can be resolved quickly.

The interactivity level between students and the lecturer might be increased by using "clicker systems", which enable students to send predefined annotations (e.g., "more explanation please") or answer multiple-choice questions during the lectures in order to test their understanding. To our knowledge clicker systems have not yet been used in a videoconference-enabled global lecture hall. Using clicker systems in such a setup may cause a high technical and administrative effort. Alternatively, a messaging system (e.g., SMS or Twitter) could be used that would enable students to send (free) text questions to the lecturer. Real-time chat, however, may be challenging due to the large number of students attending the lectures and the limited amount of time available to read and respond to each question during the lectures.

In order to make the lectures more interactive, we introduced discussion sessions in the 2010 follow-up series of the ShanghAI Lectures. After every videoconference lecture, students were asked to send their questions or topics for discussion to the lecturer by e-mail. In the following week, the students did not have to come to the classroom, but instead they logged in to UNIworld and discussed these topics with the lecturer as avatars. We were expecting that avatar-based discussions would increase students' participation levels as they reduced "social inhibition thresholds"; for instance, by eliminating visible signs of hierarchy between students and lecturers in avatar appearance, and giving those students who may be afraid to speak up in a videoconference-based global lecture hall a safe environment to ask questions as avatars via text or voice chat.

5.2 Web-based Resource

As no clear tendency was found regarding students' preferences to watch the recorded lectures individually or with their international team members, both options should be offered for the recorded lectures, which are made available after the real-time event. This way the students can decide about how and with whom to watch the lectures according to their preferences. We developed a prototype of an "in-world" video player and annotation system [Hasler, 09]. This Annotated Lectures system has been specifically designed for collaborative reviewing of video-recorded lectures using stop and play buttons, to post annotations to any part of a lecture, and to reply to annotations made by other individuals or groups.

It appears that the features which are currently available on the web-based resource are not attractive enough to keep students as active members of the embodied intelligence community. The most popular features they indicated that they would continue to use were rather passive ones (e.g., downloading and watching talks). We therefore need to add more "social networking" capabilities in order to make the web-based resource not only attractive for researchers in the field, but also for students who might not yet have scientific talks or project videos to contribute. For example, the web-based resource could also be used as a platform for companies to recruit talented students for internships, and international exchange programs relevant for the target student audience could be posted on the website. In addition, students should be given the opportunity to provide more professional information about themselves (e.g., uploading their CVs).

5.3 Collaborative Virtual Environment

According to the evaluation results and feedback on UNIworld, the advantages of this 3D CVE were often not clear to the students. Many students resorted to using traditional communication channels, such as e-mail or (video) chat instead. A major lesson we learned is that all activities in a 3D CVE should motivate and engage the users and introduce innovative ways to work and learn together. We found the Avatar-Based Collaboration Framework [Schmeil, 09b] to be a useful tool to support this approach of developing memorable experiences. Ongoing research here investigates what aspects of virtual world collaboration make it truly valuable and should thus be emphasized in the development of virtual worlds and the design of collaboration.

Since the initial project in 2009, OWL has matured considerably: It became faster and more stable, and a number of modules (extensions) have been developed that address some of the shortcomings we encountered. For instance, it is now possible to watch videos within OWL, and public, private, and group chats are now available too, if needed.

6 Conclusions

In summary, the universities were excited to participate in a lecture series they would not be able to offer otherwise, and students could broaden their horizons both on an academic as well as personal level by interacting with scholars from around the globe. By the end of the 2010 series of the ShanghAI Lectures, almost 700 students (bachelor, master, PhD) from about 50 universities signed up on the website, well over 300 of them participated actively in the exercises.

The initial project was very well received, and new editions of the ShanghAI Lectures will be rolled out on an annual basis. We hope that the ShanghAI Lectures model (the combination of videoconference, web-based resource, and 3D CVE) sees its application also for other educational content in the years to come.

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References

[Hasler, 09] Hasler, B. S., Pfeifer, R., Zbinden, A., et al.: Annotated lectures: student-instructor interaction in large-scale global education, Journal of Systemics, Cybernetics and Informatics, 2009, vol. 7, 5–9.

[Hinrichs, 11] Hinrichs, R., Wankel, C. (Eds.): Transforming virtual world learning. Cutting-edge technologies in higher education, vol. 4, Bingley, UK: Emerald, 2011.

[Pfeifer, 06] Pfeifer, R., Bongard, J. C.: How the body shapes the way we think. A new view on intelligence. Cambridge, MA: MIT Press, 2006.

[Pfeifer, 07] Pfeifer, R., Lungarella, M., Iida, F.: Self-organization, embodiment, and biologically inspired robotics, Science, 2007, vol. 313, no. 5853, 1088–1093.

[Schmeil, 09a] Schmeil, A., Eppler, M. J., Gubler, M.: An experimental comparison of 3D virtual environments and text chat as collaboration tools, Electronic Journal of Knowledge Management, 2009, vol. 7, no. 5, 637–646.

[Schmeil, 09b] Schmeil, A., Eppler, M. J.: Formalizing and promoting collaboration in 3D virtual environments – a blueprint for the creation of group interaction patterns, In Proc. First

International Conference of Facets of Virtual Environments (FaVE 2009), July 27–29, Berlin, Germany, 121–134.

[Schmeil, 10] Schmeil, A., Steinbusch, M., Jost, A., Henn, M., Jacobi, M., Schwitalla, M., Hasler, B. S.: A refined workflow for designing virtual worlds for collaborative learning. Proc. Of VS Games, March 25-26, 2010, Braga, Portugal.

[Schmeil, 12] Schmeil, A., Hasler, B. S.: Designing for Effective Collaboration Experiences in Virtual Worlds, Accepted for Publication at the Seventh IASTED Conference on Human-Computer Interaction (HCI 2012), May 14–16, Baltimore, USA.